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CHARACTERISTICS OF SELECTED FISH POPULATIONS OF ARCTIC NATIONAL WILDLIFE REFUGE COASTAL WATERS, FINAL REPORT, 1988-91

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Characteristics of Selected Fish Populations of Arctic National Wildlife Refuge Coastal Waters, Final Report, 1988-1991

by

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Abstract

We used fyke nets and hydrographic equipment from 1988 to 1991 to study fish in nearshore waters of the Arctic National Wildlife Refuge, Alaska. Crews collected data for analyses of relative abundance and distribution, size structure, condition, and age and growth for five target species: Dolly Varden char *Salvelinus malma*, Arctic cisco *Coregonus autumnalis*, Arctic flounder *Liopsetta glacialis*, fourhorn sculpin *Microcephalus quadricornis*, and Arctic cod *Boreogadus saida*. Coastal movements of the target species except for Arctic cod were examined from recaptured fish marked with dye and Floy anchor tags. Two locations were sampled within each of four specific areas: Camden Bay (Simpson Cove), Kaktovik, Jago, and Beaufort lagoons. Concurrent data on the physical habitat were also collected including water temperature, depth, salinity, and wind velocity and direction.

Dolly varden char catch per unit effort, an index of relative abundance, varied more by year than by location, although both effects were significant. The highest daily catch rates occurred in 1991, a year of cold water and heavy pack ice. Char generally were more abundant early in the open-water season. Length-frequency data indicated regular recruitment and growth as well as site-specific temporal changes in distribution. We documented changes in condition among seasons, areas and years for fish 1-13 years old, but not by gender. Age and growth data required sacrificing large numbers of fish; continuing this methodology could adversely affect older year classes. Tagged fish traveled extensively among sampling areas, coastal rivers, east into Canada, and west beyond Prudhoe Bay. Daily trends in catch per unit effort did not correlate well with physical oceanographic data. Wide distribution along the coast make char less vulnerable to local coastal perturbations; however, vulnerability may be greater for stocks required to live in or move through a particular area at a specific season (e.g. a river mouth during fall migrations). We believe that the relative abundance of individual spawning stocks cannot be accurately monitored in coastal waters; thus stocks could be reduced without detectable changes in catch per unit effort within lagoons.

Year-to-year variation in daily catch rates of small Arctic cisco ($\leq$ 200 mm FL) was greater than the spatial variation along the Arctic Refuge coast. Higher daily catch rates were observed in 1990, the year with the most persistent easterly winds. Within a sampling season, higher daily catch rates were observed for small Arctic cisco at the more easterly sampling locations in Beaufort Lagoon. For large Arctic cisco (> 200 mm FL) overall variation from area-to-area appeared to be greater than that from year-to-year. Declines in relative abundance at the end of the sampling seasons probably reflect the return of large Arctic cisco to riverine overwintering habitats. Length frequency distributions corroborated current hypotheses concerning the wind-aided westerly dispersal of young-of-the-year (YOY) and the feeding/spawning migration of large Arctic cisco. Comparisons in condition indicated difference by gender (females weighed more than similar length males) and among years (condition was lower in cold, heavy ice pack years), but seasonal and spatial comparisons were inconclusive. Age and growth analyses indicted that 1991 lengths at age 1 and 2 were smaller than those for 1989 or 1990, suggesting that growth was negatively influenced by the colder

water temperatures and minimal ice pack withdrawal. The observed westward movement of small Arctic cisco is consistent with previous findings of their migration through Arctic Refuge waters to overwintering areas in the Colville and Sagavanirktok rivers. Large Arctic cisco recaptured in the Colville River commercial fishery had moved west, instead of the hypothesized eastward movement, and were assumed to have overwintered in this river. High relative abundance in Simpson Cove was associated with high salinity and low water temperatures of marine water masses. These results may suggest that migrating large Arctic cisco do not confine themselves predominately to water masses most insulated from marine influence. Alternatively, a high index of abundance may be related to Simpson Cove's relative closeness to the overwintering areas of the Colville River.

Arctic cod relative abundance varied more among areas than among years. Simpson Cove catch rates were consistently higher than those in the other sampling areas. Daily catch rates tended to increase during the open water season. Length frequency distributions indicated the presence of one mode, corresponding to a dominant year-class, in the sampled population. Condition of Arctic cod appears to be independent of sex and location. Increases in condition observed during the sampling seasons are explained by the storage of energy reserves in preparation for winter. Corresponding overwinter declines in condition were detected. High relative body condition in 1989 may reflect the warmer, more productive ocean environment which was present that year. Age and growth analyses indicated that age 2 and age 3 fish were predominant in the sampled population. As expected, the higher catch rates of this marine species in Simpson Cove and nearshore waters in late summer coincided with lower temperatures and higher salinity.

Fourhorn sculpin were relatively abundant throughout the 1988-91 sampling seasons. Data on the little-studied fourhorn sculpin showed a lack of any strong trends in spatial or temporal variation in relative abundance. Comparisons of relative body condition indicated that in 1989 females weighed more than males of similar length and that strong annual differences existed (i.e., low condition in cold, heavy ice-pack years). Seasonal and spatial differences in body condition were inconclusive. Consistent recruitment and growth were indicated by the trimodal length frequency distributions, corresponding to fish age 1, age 2, and age 3. Tag-recapture results indicated that approximately 89% of the recaptures occurred within the original tagging area consistent with previous observations of localized movements. Trophic-mediated movements may be the primary determinant of fourhorn sculpin distributions.

Arctic flounder abundance along the Arctic Refuge coast varied more among years than among sampling areas. Reproductive success may have been much greater in the latter two years of the study, which would account for the large among-year variability and the relative ranking of mean annual catch rates. Within a sampling season, observed fluctuations in daily catch rates are consistent with the occurrence of inshore/offshore movements noted by other researchers. During 1988 and 1989 a higher percentage of fish 200-250 mm TL were noted; whereas, more 50-150 mm TL fish were present during 1990 and 1991. Comparisons of relative body condition indicated higher weight at a given length for some treatment groups as follows: 1) female weights were higher than males; 2) late collected fish weighed more than early season fish; and 3) pre-winter fish weighed more than post-winter fish. Some among areas differences in body condition were noted as well as among years (i.e., low condition was observed in years of cold water temperature and heavy ice pack). Arctic flounder were found to be as old as age 18. Two modes, age 2 and age 3 dominated the age distribution. Tag-recapture results indicated that 93% of the recaptures occurred within the original tagging area. This was consistent with previous observations of localized movement of Arctic flounder. Analyses of environmental influences on CPUE indicated an overall trend of decreasing daily catch rates toward the end of the sampling season as water temperatures dropped and salinities increased.

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Preface

The four years of data collection during this study resulted in the collection of over 265,000 new data records on Arctic fishes. Some of the species included herein have not had intensive study in Alaska or elsewhere in the northern polar region. The result is a substantial increase in our understanding of the population characteristics of some of these species. Despite these significant advances, this study, similar to most baseline studies, is limited in its predictive capabilities. In essence, our study only describes the pre-development status in a pre-development/post-development scenario (i.e., development has yet to occur). Specific statements about the effects of oil development cannot be inferred from our data because no hypotheses were tested regarding such development. Predictive capabilities and definitive statements remain limited to known effects found in applicable scientific literature and case histories. Therefore, one purpose of the study was to establish a baseline dataset; a second purpose was to determine how that baseline is related to other data in the scientific literature.

In contrast, studies conducted since 1985 in the Prudhoe Bay region present the post-development data (Gallaway et al. 1991). Data collected prior to causeway construction were referenced as baseline data, but not often used for hypothesis testing. These studies only evaluated changes occurring after the construction of the Endicott and West Dock causeways. Left neglected were critical comparisons of before versus after; problems of relevance and applicability resulted from the lack of pre-construction data, linked by a common study design, to data collected after construction. Confusion was increased, according to Howarth (1991), because distinction is lacking between "observing of 'no statistically detectable effect' and concluding that there is 'no effect' when our methods of detection are so poor" (i.e., lack of statistical power). Unfortunately, this distinction, between not detecting an effect and concluding that an effect does not exist, is often not understood by the casual reader and general public. These problems and others continue to cause doubt for some professionals (Hachmeister et al. 1991) concerning conclusion of no significant impacts (Gallaway et al. 1991). Disputes about the results of this study are also inevitable such that we believe a clear statement of our methodology was as important as the baseline data itself.

Some readers may be expecting definitive statements regarding the effects of oil development on fish populations. It is imperative that the audience understand the limitations of baseline studies and the scientific literature currently available. Some direct impacts, such as the effects of hydrocarbons on exposed fish, are well documented for some species and can be reasonably applied to potential outcomes on the Arctic National Wildlife Refuge. Other potential impacts, whether positive or negative, lack supporting evidence. In these cases definitive statements are not appropriate; however, issues of concern warrant some discussion in the Management Summary (below).

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Management Summary

Introduction

Fish populations in coastal waters of the Arctic National Wildlife Refuge (Arctic Refuge) have survived Arctic conditions by adapting their life histories to specific ecological niches. Specialized species are often sensitive to environmental change and the potential for environmental change increased greatly with the discovery of oil near Prudhoe Bay in 1968. In recent years groups interested in oil development worked toward opening Arctic Refuge lands to oil production on the coastal plain. This potential development highlighted the need for additional biological information.

Biologists collected baseline data between 1988 and 1991 on fish and their habitats in the nearshore waters of the Arctic Refuge. We described population characteristics for five species by estimating parameters, hypothesis testing, graphical depictions, and descriptions of variation sources within populations. The study provided baseline information critical to management agencies by documenting which fish are present in an area, by determining some measurable population characteristics, and by identifying habitats necessary to some populations. Specific objectives were as follows:

(1) Determine relative abundance, distribution, and movement patterns for anadromous and marine fish species.

(2) Determine length frequency, age structure, weight-length relationships, and condition for Dolly Varden char, Arctic cisco, Arctic cod, fourhorn sculpin, and Arctic flounder in Arctic Refuge coastal waters.

(3) Characterize the sampling areas in terms of water temperature and salinity.

(4) Delineate current patterns offshore from the Simpson Cove and Beaufort Lagoon sampling areas.

(5) Examine the relationships of salinity, temperature, and current patterns to wind direction and velocity in the sampling areas.

(6) Test the hypothesis that relationships exist between catch per unit effort (CPUE) and hydrographic characteristics; and determine the nature of these relationships.

Our report describes fish population characteristics, natural processes, and critical habitats of the Arctic Refuge nearshore coastal waters (Objective 1,2 and 6). The fish population characteristics are reported in the technically-oriented chapters found in this publication. Smaller localized descriptions of oceanographic conditions (Objective 3-5) from a limited quantity of physical oceanographic and meteorologic data collected by U.S. Fish and Wildlife Service were reported by cooperators in separate reports (Hale 1990, 1991). Descriptions of large-scale natural processes such as movement and effects of ocean currents, advection, upwelling, nutrient source and movements, are discussed only as related to population characteristics. For in-depth descriptions of oceanographic processes, a reader should seek out the referenced scientific literature. In some cases the biological importance of these natural processes and critical habitats is not obvious. Discussions of natural processes and critical habitats are not explicit in the technical chapters, but are included in this Management Summary (below).

The Coastal Aquatic Environment and Arctic Fishes

The following overview of the physical environment of the Beaufort Sea coast and its influence on the fish community is adapted from several sources, including Cannon et al. (1987); Craig (1984, 1989); Craig and Haldorson (1980); Gallaway et al. (1991); Hale (1990, 1991); and Thorsteinson et al. (1991).

The Coastal Habitat

The annual hydrographic cycle of the Alaskan Beaufort Sea coast brings relatively dramatic, although predictable, changes to the nearshore habitat. Wind, freshwater runoff, and ice are the physical entities which most influence coastal hydrography, due primarily to the bathymetry caused by the gentle slope of the inner continental shelf. Ice covers the shelf for nine months a year, usually from October through June, with a shorefast ice zone freezing to a depth of about 2 m and extending roughly to the 20 m isobath (Sharma 1979). Anadromous fish are presumably absent from these coastal waters during this period, and resident marine forms are forced to seek deeper waters during the Arctic winter. An ice-free shoreline zone is generally present from June to September, during which time wind and freshwater runoff interact to form a unique nearshore aquatic corridor which figures prominently in the life history of regional fish stocks. Numerous resident marine and anadromous species use this coastal boundary layer for migratory and feeding purposes during the brief Arctic summer. Consequently, the processes which generate and modify this ephemeral habitat deserve increased attention.

A large number of streams and rivers discharge fresh water into the Canadian and Alaskan Beaufort Sea, dominated by the Mackenzie River to the east and the Colville River to the west. The period of freshwater influence begins at break-up on the coastal plain every spring, peaks in June, and tapers off gradually as summer progresses. The freshwater runoff mixes with nearshore marine water to form a relatively warm, brackish nearshore water mass which tends to persist along the coast in varying horizontal and vertical dimensions. Maintenance of this discrete boundary layer is influenced primarily by wind patterns and shoreline topography. Water currents over the nearshore shelf are primarily wind-driven, with little opportunity for strong vertical stratification during early summer. As summer progresses, freshwater input declines, thermal and density gradients break down, the mixing forces of wind friction and Coriolis continue, and the influence of offshore marine water becomes more evident in nearshore areas. Frequent easterly/westerly wind reversals hasten the advection of marine water masses into nearshore lagoon systems (Hale 1990, 1991).

Combinations of climatological patterns periodically cause offshore pack ice to remain relatively close to the coast throughout the brief summer season. Such was the case during the 1988 and 1991 sampling seasons for this study. While the effects are variable, water temperatures generally remain below those observed during a "normal" year, when the ice pack recedes beyond the 20-m isobath. Increased vertical stratification may also be expected because of restricted mixing of the water column from wind. The effect of these periodic ice events on the fishery resources using the coastal corridor is largely unknown.

Little published information exists on the rates of primary production in the Alaskan Arctic aquatic environment. Coastal rivers introduce large quantities of inorganic and organic sediment to the Beaufort Sea during early summer. Augmenting the detrital input are the thermoerosion of bluffs and the subsidence and subsequent inundation of shoreline regions. Resuspension of bottom sediments by ice gouging has also been reported (Sharma 1979) and may contribute to nutrient recycling.

Prior to its dissolution in fall, the warm brackish boundary layer serves as a migration corridor and feeding and rearing habitat for anadromous fish stocks. The open-water period of roughly three months duration is when anadromous fishes accumulate energy reserves for subsequent overwintering and reproductive activities. Compared to other seasonally available habitats, prey items for anadromous fish, primarily epibenthic mysids and amphipods, are abundant in the nearshore coastal waters.

The brackish corridor is thought to provide an avenue for the westward distribution of young Arctic cisco spawned in the Mackenzie River, plus the eastward return of the mature adults for spawning (Gallaway et al. 1983). This dispersal necessarily includes transport across the coast of the Arctic Refuge, which accounts for the occurrence of the large numbers of small Arctic cisco observed in this study. That the westward dispersal of young Arctic cisco is wind-aided (Fechhelm and Fissel 1988) is corroborated by the catch and wind data presented herein. The hypothesized mechanism accounts for the gross annual trends observed in our data. The variability in daily trends remains largely unexplained.

Resident marine species may also be influenced by the hydrodynamics of the warmer coastal boundary layer. The summer distribution of Arctic cod in the Prudhoe Bay area was found to be associated with the transition layer between intruding marine water masses and the brackish coastal corridor (Moulton and Tarbox 1987). While our sampling methodology was unable to detect movements of this resolution, we did find Arctic cod were more abundant at those stations which were most influenced by offshore water masses (i.e., Simpson Cove). Similarly, Arctic cod were present in higher densities during the latter half of the sampling periods, coincident with the increased intrusion of marine water into the nearshore area. In this case, coastal hydrology influences the distribution of a major prey species in the Alaskan Beaufort

Sea, with potentially significant effects on the biota of the nearshore waters.

Fish Assemblages

The onset of colder water temperatures and higher salinities in late fall mark the division of several fish assemblages as they move to their overwintering habitats. Marine fishes gradually move offshore past the two meter water depth or maximum ice depth. Marine habitat is expansive and the marine fish assemblage is not thought to be limited by winter habitat. Anadromous fishes move into coastal rivers and tributaries. Anadromous overwintering areas are few, separated geographically, and thought to be population limiting.

Overwintering areas for anadromous fish on the North Slope are divided into brackish water delta areas of the largest rivers, the Mackenzie, Sagavanirktok, and Colville, and freshwater areas, most often associated with spring-fed stream reaches and deep pools. The interaction of coastal geography and differential preferences for overwintering sites has led to the characterization of distinct zones of the Beaufort Sea coast based on the further division of the two anadromous fish assemblages (Figure 1). The Mackenzie and Colville river deltas and surrounding areas are characterized as whitefish and least cisco habitat, while a portion of the coast between these two systems, from the Alaska-Canada border west to the Sagavanirktok River, is characterized as Dolly Varden char and temporary Arctic cisco habitat.

The regional associations described above reflect an apparent difference in preferred summer foraging habitats and migratory behavior between the two assemblages, with the cisco/whitefish group preferring to remain near the more protected, freshwater deltaic zones. Least cisco and the whitefish complex are known to spawn and overwinter in the western Beaufort Sea area between Barrow and the Sagavanirktok River, as well as in the Mackenzie River drainage. While Arctic cisco are believed to spawn only in the Mackenzie River drainage, pre-spawning juveniles and adults overwinter in larger Alaskan North Slope rivers. Evidence suggests that young-of-the-year cisco and whitefish prey upon chironomid larvae and zooplankton, while overwintering adults in the deltaic regions eat epibenthic invertebrates.

Dolly Varden char, on the other hand, are less deterred by the more exposed eastern Alaska Beaufort Sea coastline and, beginning in August, ascend many of the larger Alaskan North Slope rivers (e.g., the Kongakut, Canning, Sagavanirktok rivers) into free-flowing spring areas for overwintering and spawning. Numerous rivers containing overwintering and spawning sites for Dolly Varden char were identified in McCart (1980). Most overwintering is associated with spring-fed areas of rivers and tributaries originating in the Brooks Range between the Babbage River (Canada) and the Sagavanirktok River. Overwintering and spawning habitat is limited to those stream reaches that remain free-flowing (with or without ice cover) throughout winter, although the two activities are often spatially segregated. Pre-smolts in freshwater prey upon benthic invertebrates. Although feeding during freshwater migration and spawning is thought to be negligible, overwintering adults may augment an

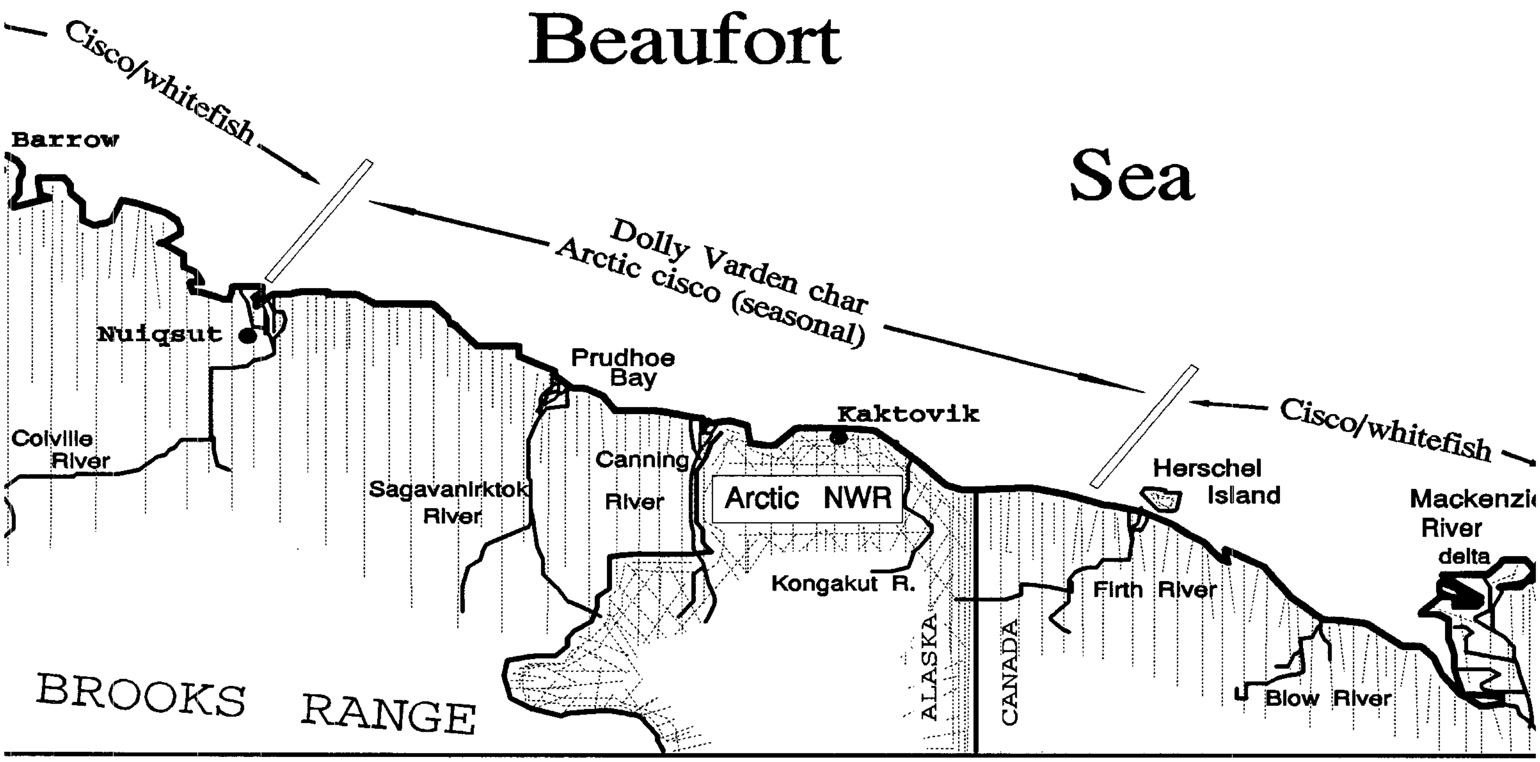

FIGURE 1.— Schematic map of generalized habitat zones, as characterized by the dominant anadromous fish assemblages found in coastal and freshwater habitats in and around the Arctic Refuge (adapted from Craig 1989).

invertebrate diet with small fish and fish eggs during the latter part of their freshwater residency.

The duration of the freshwater residency period for both Dolly Varden char and Arctic cisco varies annually and by life stage. Pre-smolts Dolly Varden char remain in freshwater for one to four years before entering coastal waters for foraging. Evidence suggests that density-dependent factors (e.g., food availability) may influence the onset of anadromous behavior of char. In contrast, young-of-the-year Arctic cisco wash into brackish water with breakup flows of the MacKenzie River, a density independent process. Overwintering non-spawning Dolly Varden char and Arctic cisco wait for a suitably free-flowing water before entering the coastal boundary layer in spring. Dates of departure from the overwintering grounds is dependent on the environmental conditions and is followed by summer feeding in nearshore waters. Spawners exhibit similar departure patterns from overwintering areas, but in contrast, are believed to travel to and remain in or near their freshwater spawning area throughout the summer preceding the spawning event. As such, the number and the timing of anadromous fish entering coastal waters each spring and behavior following entry is a complex interaction of biotic and abiotic factors.

Target Species

We identified five "target species" for analyses of specific population characteristics. Previous studies indicated these species were appropriate for additional study (West and Wiswar 1985; Wiswar and West 1987). Target species represented anadromous and marine species that were: (1) present at all sampling areas, (2) generally abundant, (3) readily sampled by fyke nets, (4) important for subsistence or commercial fishing. The five species were Dolly Varden char *Salvelinus malma*, Arctic cisco *Coregonus autumnalis*, Arctic cod *Boreogadus saida*, fourhorn sculpin *Myoxocephalus quadricornis*, and Arctic flounder *Liopsetta glacialis*.

Dolly Varden char

Advances were made regarding the biology and population characteristics of Dolly Varden char within the Arctic Refuge. We found our index of relative abundance varied more by year than by location, although both effects were significant. The highest daily catch rates occurred in 1991, a year of cold water and heavy pack ice. Char generally were more abundant early in the open-water season. We believe the relative abundance of individual spawning stocks cannot be accurately monitored in coastal waters and stocks could be reduced without detectable changes in catch per unit effort within lagoons. Length frequency data indicated regular recruitment and growth as well as site-specific temporal changes in distribution. We documented changes in fish condition among areas and years, but not by gender or season. Char ranged from 1 to 13 years old. Age and growth data required sacrificing large numbers of fish and continuing this methodology could negatively affect older age groups of fish. Tagged fish travelled extensively among sampling areas, into coastal rivers, and beyond the Arctic Refuge, eastward into Canada and westward past Prudhoe Bay. Wide distribution along the coast make char less vulnerable to local coastal perturbation except for stocks required to move through a particular area (such as a river mouths) during fall migrations. Physical oceanographic data (salinity, temperature, wind velocity) did not correlate well with daily trends in CPUE observations in most instances.

Arctic cisco

Year-to-year variation in daily catch rates of small Arctic cisco (≤ 200 mm FL) was greater than the spatial variation along the Arctic Refuge coast. Higher daily catch rates were observed in 1990, the year with the most persistent easterly winds. Within a sampling season, higher daily catch rates were observed for small Arctic cisco at the more easterly sampling locations in Beaufort Lagoon. For large Arctic cisco (> 200 mm FL) overall variation from area-to-area appeared to be greater than that from year-to-year. Declines in relative abundance at the end of the sampling seasons probably reflect the return of large Arctic cisco to riverine overwintering habitats. Length frequency distributions corroborated current hypotheses concerning the wind-aided westerly dispersal of young-of-the-year (YOY) and the feeding/spawning migration of large Arctic cisco. Comparisons in condition indicated difference by gender (females weighed more than similar length males) and among years (condition was lower in cold, heavy ice pack years), but seasonal and spatial comparisons were inconclusive. Age and growth analyses indicted that 1991 lengths at age 1 and 2 were smaller than those for 1989 or 1990, suggesting that growth was negatively influenced by the colder water temperatures and minimal ice pack withdrawal. The observed westward movement of small Arctic cisco is consistent with previous findings of their migration through Arctic Refuge waters to overwintering areas in the Colville and Sagavanirktok rivers. Large Arctic cisco recaptured in the Colville River commercial fishery had moved west, instead of the hypothesized eastward movement, and were assumed to have overwintered in this river. High relative abundance in Simpson Cove was associated with high salinity and low water temperatures of marine water masses. These results may suggest that migrating large Arctic cisco do not confine themselves predominately to water masses most insulated from marine influence. Alternatively, a high index of abundance may be related to Simpson Cove's relative closeness to the overwintering areas of the Colville River.

Arctic cod

Relative abundance of Arctic cod varied more among areas than among years. Simpson Cove catch rates were consistently higher than those in the other sampling areas. Daily catch rates tended to increase during the open water season. Length frequency distributions indicated the presence of one mode, corresponding to a dominant year-class, in the sampled population. Condition of Arctic cod appears to be independent of sex and location. Increases in condition observed during the sampling seasons are explained by the storage of energy reserves in preparation for winter. Corresponding overwinter declines in condition were detected. Higher relative body condition in 1989 may reflect the warmer, more productive ocean environment which was present that year. Age and growth analyses indicated that age-2 and age-3 fish were predominant in the sampled population. As expected, the higher catch rates of this marine species in Simpson Cove and nearshore waters in late summer coincided with lower temperatures and higher salinity.

Fourhorn sculpin

Fourhorn sculpin were relatively abundant throughout the 1988-91 sampling seasons. Data on the little-studied fourhorn sculpin showed a lack of any strong trends in spatial or temporal variation in relative abundance. Comparisons of relative body condition indicated that in 1989 females weighed more than males of similar length and that strong annual differences existed (i.e., low condition in cold, heavy ice-pack years). Seasonal and spatial differences in body condition were inconclusive. Consistent recruitment and growth were indicated by the trimodal length frequency distributions, corresponding to fish age 1, age 2, and age 3. Tag-recapture results indicated that approximately 89% of the recaptures occurred within the original tagging area consistent with previous observations of localized movements. Trophic-mediated movements may be the primary determinant of fourhorn sculpin distributions.

Arctic flounder

Indices of abundance of Arctic flounder along the Arctic Refuge coast varied more among years than among sampling areas. Reproductive success may have been much greater in the latter two years of the study, which would account for the large among-year variability and the relative ranking of mean annual catch rates. Within a sampling season, observed fluctuations in daily catch rates are consistent with the occurrence of inshore/offshore movements noted by other researchers. During 1988 and 1989 a higher percentage of fish 200-250 mm TL were noted; whereas, more 50-150 mm TL fish were present during 1990 and 1991. Comparisons of relative body condition indicated higher weight at a given length for some treatment groups as follows: 1) female weights were higher than males; 2) late collected fish weighed more than early season fish; and 3) pre-winter fish weighed more than post-winter fish. Some among areas differences in body condition were noted as well as among years (i.e., low condition was observed in years of cold water temperature and heavy ice pack). Arctic flounder were found to be as old as age-18. Two modes, age-2 and age-3 dominated the age distribution. Tag-recapture results indicated that 93% of the recaptures occurred within the original tagging area. This was consistent with previous observations of localized movement of Arctic flounder. Analyses of environmental influences on CPUE indicated an overall trend of decreasing daily catch rates toward the end of the sampling season as water temperatures dropped and salinities increased.

Issues of concern

Critical habitats

Two habitats found on the Arctic Refuge can be described as critical to fishes using the nearshore coastal waters: 1) overwintering river habitat of Dolly Varden char, and 2) coastal lagoons. Dolly Varden char must cope with a profound reduction in available habitat during winter freeze-up. Suitable overwintering and spawning habitat is almost certainly the most "critical", in the sense that perturbations or abnormal conditions affecting a relatively small area may have far-reaching consequences for local stocks of Dolly Varden char. Encroachment of ice in deep pools in the absence of insulative snow-cover or dewatering of habitat downstream of springs due to *aufeis* formations may significantly reduce the volume of available overwintering habitat. Alternative sites may be isolated by intervening reaches of solid ice, such that an initial "mistake" in selection of an overwintering site may result in a total or near total loss of the individuals. In short, having entered their chosen freshwater system for spawning and overwintering, char are relatively restricted in their options for contending with natural or human induced habitat degradations. The increased sensitivity of char stocks during this freshwater residency period should be considered before undertaking any activities which alter or disturb the fluvial habitats of the Alaskan North Slope.

Coastal lagoons provide warm and highly productive refuges from the extremely low temperature water of the Arctic Ocean. Warmer water temperatures are associated with higher growth. As such, the lagoons provide opportunities for enhanced growth which would be unavailable if the fish were obligated to contend strictly with marine conditions during their residence in coastal waters. Some coastal development structures, such as gravel filled causeways, "...provide an alternative mechanism by which high-salinity, cold bottom water can be carried to the surface, mixed, and advected away from the structure by the wind," (Gallaway et al. 1991). Many North Slope biologists agree that habitat changes have occurred due to coastal development, but disagree on the biological significance of those changes. Gallaway et al. (1991) maintain "... the possibility that fish are suffering severe negative effects from the Endicott Causeway seems low." In contrast, Hachmeister et al. (1991) suggested that measurable effects on the growth rates and age structure of fish populations have occurred. As mentioned earlier, the distinction between an analysis of post-development data only (Gallaway et al. 1991), as opposed to a formal attempt to compare pre-development and post-development data, must be considered when interpreting results. Regardless of the controversy concerning the biological significance of coastal development structures, there exists an implicit agreement that preserving the integrity of the warmer, brackish coastal boundary layer during summer months is crucial for sustaining the biota of the region. In this context, the brackish nearshore corridor should be considered critical to the success of marine and anadromous fish stocks. In addition, freshwater flows from coastal rivers and streams are crucial to the creation of the brackish water zone and it is imperative to maintain natural flows to avoid impacts.

Subsistence harvest

Fourteen species of marine and freshwater fish are harvested by subsistence fishers on the Arctic Refuge and comprise up to 19% of the harvested resources for the village of Kaktovik (Pedersen 1990). Arctic cisco and Dolly Varden char make up the majority of the harvest, emphasizing the importance of these stocks as sources of protein for the local inhabitants. Char and cisco are harvested during a summer net fishery at various fish camps along the coast. In addition, char are collected in overwintering sites in the Hulahula and Kongakut rivers during the winter. Site-specific construction should consider possible affects on the subsistence harvest.

Site-specific impacts

Our data showed that fish distribution and physical habitat characteristics varied from site to site along the Arctic refuge coast. The nature and extent of hydrographic changes caused by a particular structure or activity would also be expected to be site-specific. If specific development projects become imminent, pertinent pre- and post-development data should be gathered from the identified site. A random sampling design within the potentially affected area (as opposed to sampling at fixed net locations) would allow inferences to be made about the entire development site.

Cumulative impacts

Incremental environmental changes caused by the proliferation of nearshore development projects are of concern. Each gravel-filled causeway creates new hydraulic features which may cause upwelling of cold marine water (Gallaway et al. 1991) and alter the fish habitat (Hachmeister et al. 1991). Colder temperatures can negatively affect fish growth (Griffiths et al. 1992) and impede normal migration patterns, but it remains unclear whether or not these potential effects are biologically significant. It is also uncertain if the potentially deleterious effects of additional cold water intrusion into the nearshore area would be cumulative in the event that more development projects were added.

Offshore oil development

Oil exploration continues in the Beaufort Sea adjacent to refuge lands. Exploratory wells have revealed significant deposits of oil on Federal lease sites within 26 km of the shore. Wind-driven ocean currents of 11.3 to 33 cm/s (Hale 1991) could bring spilled oil onto Arctic Refuge lands within two to six days. Offshore development is a concern in light of the uncertainty of quantifying the impact of spills on the environment and the continued underestimate of harm from petroleum releases (Howarth 1991). Currently, no oil spill contingency plan has been developed for refuge coastal areas.

Contaminant spills

Contaminant spills from petroleum development activities are of particular concern in the Arctic environment. Impacts are compounded when exposure time is increased due to the slower volatilization and degradation which occurs in extreme cold water temperatures. Prolonged exposure times are critical given that petroleum hydrocarbons are incorporated into fish tissue relatively quickly (Lee 1977). The water-soluble fraction of oil is toxic at high concentrations and, at lower concentrations, negatively impacts reproduction, development, growth, and/or behavior of fish, crustaceans, and mollusks. In addition, oil trapped under the ice may be very persistent in the environment (Carls and Korn 1985).

Adequacy of baseline data

The study reported here produced volumes of data, possibly more than other pre-development North Slope coastal fisheries study. Despite this fact, the high natural variation found in the Arctic ecosystem, plus the steep learning curve inherent to working in coastal waters, renders our baseline data as only a beginning step in efforts to monitor the long-term effects of development. Consultation with oil industry biologists as well as those biologists working in the Canadian Arctic suggest that a database covering at least ten years is necessary for monitoring potential changes associated with coastal development activities.

Recommendations

1. We recommend special consideration of lagoon systems as essential habitat to ensure their protection. The lagoons are uniquely important to the rearing of many marine and anadromous fish species. Changes in the quantity or quality of these warm and highly productive habitats would impact directly on the growth and rearing capacity of these systems. Unique water quality and circulation patterns in each lagoon may be especially important for maintaining the diversity of coastal habitats and fauna.

2. We recommend that overwintering habitat for Dolly Varden char be preserved in quantity and quality. Winter habitat, isolated pockets of fresh water in coastal rivers, may limit Dolly Varden char populations. These isolated pockets are few, limited in size, and subject to poor water quality due to low oxygen groundwater, limited water exchange, and crowding. Char are most vulnerable to extirpation while restricted to these isolated pockets of habitat. Surface and ground water withdrawals could reduce flows resulting in reduced water quality or complete freezing of overwintering areas.

3. We recommend that freshwater discharge from coastal streams and rivers be maintained in quantity, quality, and timing. The brackish water coastal zone critical to marine and anadromous Arctic fishes is created by interactions of fresh and marine water masses. The volume of the brackish water habitat is directly related to the quantity, quality, and timing of freshwater inputs. Reductions in water quantity (discharge) would result in corresponding reductions in brackish water habitat and production. Water quality related to sediment transport to deltas and nearshore habitats may be important. Flow timing plays an important role in lateral dispersal of the fresh water along the coast. High spring discharge also initiates and aids break-up of coastal ice which signals the beginning of the growing season.

4. We recommend a peer review of project methodology, development of an improved study protocol, and continued sampling along the Arctic refuge coast to develop further the baseline database. A peer reviewed study plan would improve the study design. In addition, discussions with other agency and industry personnel with experience in Arctic fish biology have led to the consensus that a database of ten years duration is the minimum needed to describe the biotic and abiotic variation in Arctic coastal environments.

5. We recommend that, if development is approved, a fisheries oil spill monitoring contingency plan be developed in conjunction with National Oceanic and Atmospheric Administration agencies. Exploratory oil drilling continues on State and Federal leases in the Beaufort Sea near the Arctic Refuge. The Alaska Federal/State Preparedness Plan for Response to Oil and Hazardous Substance Discharges/Releases (Unified Plan - Volume I) completed May 1994,

establishes a North Slope Region/Sub Area Contingency Plan (Volume II) planning area including the Beaufort Sea. North Slope planning currently combines the efforts of the U.S. Fish and Wildlife Service (Service), the National Marine Fisheries Service, and the Alaska Department of Fish and Game to rank the importance of fish, wildlife and sensitive areas of concern. Specific response options available to protect Beaufort Sea fisheries' resources will be addressed using the available fisheries data and the Service's "Wildlife Response Plan: Fisheries May 2, 1994."

6. <u>We recommend accurate indices of Dolly Varden char abundance be developed for specific river or spawning stocks and monitored for three to five years, followed by subsequent periodic monitoring</u>. Abundance of anadromous char is a concern because of their importance as a subsistence and sport fish. Dolly Varden char are the only subsistence species reproducing and overwintering on Arctic Refuge lands. Catch per unit effort (CPUE) data collected in the lagoon systems may not reflect catastrophic stock decline nor incremental declines (e.g., sport or subsistence harvest) because of high variation and mixing of off-refuge stocks. Available data from aerial surveys do not appear to be accurate or precise enough for use by resource managers.

7. <u>Spawning and overwintering ecology of Dolly Varden char should be studied intensively</u>. In general, the density-dependent and density-independent factors which influence survival of eggs, fry, and pre-smolts in North Slope rivers are poorly understood. McCart (1980) identified several Dolly Varden char spawning and overwintering areas within Arctic Refuge boundaries. While most biologists agree that resources are limited during the eight-month freshwater residency period, little is known about the specific biotic and abiotic mechanisms which influence successful recruitment to the smolt stage. Investigating the biological interactions of spawning and non-spawning Dolly Varden char during winter may lead to increased understanding of the population dynamics of the stock. Evidence suggests that overwintering non-spawners remain spatially segregated from current spawners (Yoshihara 1972, 1973). Decreased opportunities for segregation may result from habitat perturbations and cause potentially significant consequences on spawning success.

8. <u>Investigations are needed to develop an understanding of habitat use by migrating/foraging young-of-the-year (YOY) Arctic cisco</u>. Little is known about the fate of YOY Arctic cisco which do not reach the Colville River system for overwintering after their initial entry into Alaskan coastal waters for foraging. These fish are believed to be transported westward from the Mackenzie River across the Arctic Refuge coast, presumably by wind-induced coastal currents. In years when east winds are weak or intermittent, fewer young Arctic cisco have been observed entering the Prudhoe Bay area. Biologists have suggested that overwintering may take place on refuge lands, perhaps in the Hulahula or Canning river deltas. If this is true, these areas may be critical habitat for young Arctic cisco unable to reach the Sagavanirktok or Colville river overwintering areas.

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Chapter 1 Project Justification and Design

Introduction

Fish populations on the Arctic National Wildlife Refuge (Arctic Refuge) have evolved specialized life strategies that enable them to survive severe Arctic conditions. Anadromous and marine species capitalize on the few opportunities for growth and reproduction while minimizing exposure to the harsh elements of the Arctic. Like most Arctic species, the fishes of the Arctic Refuge inhabit specific ecological niches (Craig 1989). Complex interactions between aquatic organisms and the wind, sea, rivers, and terrestrial environment increase the difficulty of isolating the effects of change on fish populations. Natural or man-induced changes to this web of interactions could prove harmful to these specialized populations.

The discovery of oil near Prudhoe Bay in 1968 increased national attention on the possibility of recovering commercial quantities of oil and gas from the Arctic Refuge coastal plain (Figure 1.1). A report to the U.S. Congress (Clough et al. 1987) quoted a 19% chance of finding economically recoverable oil and gas and described possible extraction and transportation scenarios for these resources. Section 1003 of the Alaska National Interest Lands Conservation Act currently prohibits oil and gas leasing on the refuge. However, legislation allowed seismic exploration during the winters of 1984 and 1985. In addition to possible oil production on the coastal plain, several oil leases have been sold in offshore state and federal waters adjacent to the Arctic Refuge since the early 1980's. Exploratory drilling led to the discovery of oil in some of these areas and exploration continues in offshore waters. Production of oil and gas on the coastal plain and development of coastal support facilities may occur in the future.

Anadromous and marine fish species feed in lagoons and other nearshore brackish waters of the Beaufort Sea during the summer months (Craig 1984; Frugé et al. 1989; Palmer and Dugan 1990). A brackish water band forms along the Beaufort Sea coast as a result of snow and ice melt in spring. Density gradients keep the freshwater from mixing readily with high salinity marine water and west winds tend to hold this layer of brackish water against the coast (Craig 1984). These areas are important because they are warmer than offshore Beaufort Sea waters and have a high prey concentration (Craig 1984). These conditions optimize feeding opportunities for fishes, enabling them to accumulate fat reserves essential for overwintering and reproduction. The nearshore brackish band also serves as an important migratory pathway for several anadromous species (Craig 1984; Frugé et al. 1989; Palmer and Dugan 1990). According to Craig (1984) salinity and temperature are the physical factors of greatest importance to fishes in these nearshore waters. These factors are determined in part by nearshore, wind-driven ocean currents (Sharma 1979; Hale 1990, 1991).

Oil, gas, and port site developments within Arctic Refuge coastal waters have the potential to affect Arctic fish populations. Inadvertent spills of

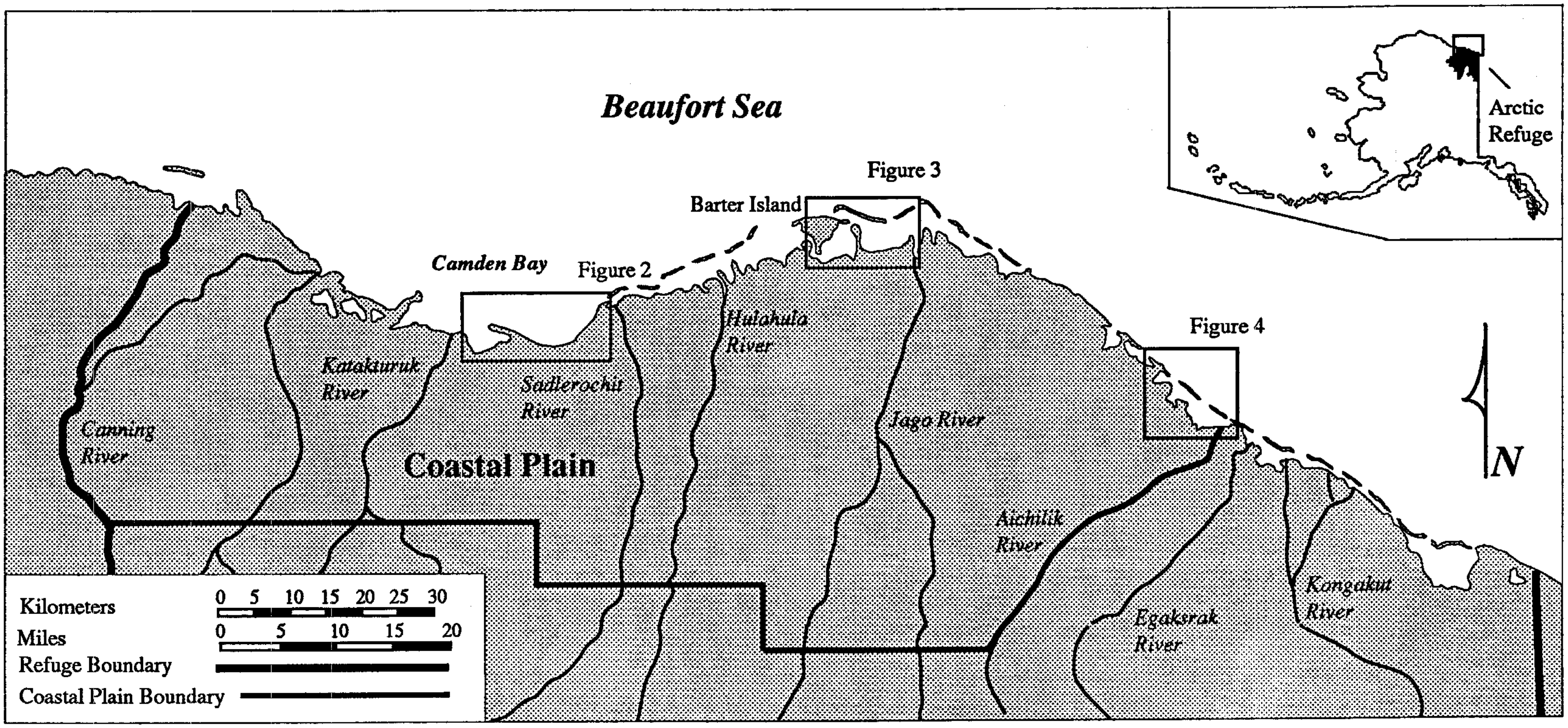

FIGURE 1.1– Beaufort Sea coast and coastal plain of the Arctic Refuge and areas sampled for fish and physical hydrographic characteristics during mid-July through mid-September, 1988-91.

oil and other hazardous materials may affect local fish populations directly. Indirect effects may result from the construction and operation of multiple causeways, port sites, and/or water intake facilities. Such developments may alter environmental conditions of coastal waters and degrade critical fish habitats (Craig 1984; Hachmeister et al. 1991).

Fish studies in Arctic Refuge coastal waters began in the summer of 1970 with a gill net survey that spanned the entire Arctic Refuge coast (Roguski and Komarek 1971). Early data from coastal waters, including Kaktovik Lagoon, were also collected in the 1970's by Ward and Craig (1974) and Griffiths et al. (1977) in response to a proposed gas pipeline across the refuge. In 1982, Griffiths (1983) studied Beaufort and Angun lagoons as part of a biological survey of eastern Beaufort Sea lagoons. Craig (1983) sampled Kaktovik Lagoon during the summer of 1983 to monitor effects of gravel dredging on the east shore of Barter Island. Kaktovik Lagoon was also sampled with fyke nets in 1985 as part of a study of the local subsistence fishery (Nelson et al. 1986). The U.S. Fish and Wildlife Service (Service) began sampling Arctic Refuge coastal waters with fyke nets in Beaufort Lagoon during the summers of 1984 and 1985 (West and Wiswar 1985; Wiswar and West 1987), Oruktalik Lagoon in 1986 (Wiswar et al., in preparation), and western Camden Bay in 1987 (Wiswar and Frugé, in preparation).

Although the above studies resulted in fisheries information from Arctic Refuge coastal waters, none provided adequate site-specific or time series data on fish use of areas identified as possible port sites by Clough et al. (1987). Also, the studies did not address the potentially large annual variability in fish distribution and abundance common to Arctic populations (Craig 1984). To fully assess potential impacts on local fish populations, the Service needed data on fish distribution and abundance and related hydrographic characteristics over a multi-year period. Such information would also assist in designing and situating coastal structures and activities of the oil industry while protecting critical fish habitats and migration corridors.

For these reasons, we initiated a five-year study in 1988 to collect baseline data on the fish species using the coastal waters of the Arctic Refuge. We gathered baseline data to document characteristics of coastal fish populations that could be used to: (1) help oil development strategies avoid or minimize impacts; (2) steer future monitoring efforts; (3) suggest development-related mitigative measures; and (4) foster an understanding of the biological processes occurring in the coastal waters of the Arctic Refuge.

We established four sampling areas in 1988 (Frugé et al. 1989). Two of these areas, Simpson Cove and the coastal waters near the bluffs west of Pokok Bay, were potential port sites. The two additional sampling areas, Kaktovik and Jago lagoons, were located near Barter Island. Due to heavy pack ice close to shore at the Pokok "bluffs" area for most of the summer in 1988, we abandoned this sampling area in 1989. Beaufort Lagoon, approximately 19 km east, replaced Pokok Bay as a sampling area in 1989.

We selected Beaufort Lagoon because data were collected at this location in 1984 and 1985 (West and Wiswar 1985; Wiswar and West 1987). This area is also protected by barrier islands; therefore, it can be sampled despite pack ice conditions. In 1990 and 1991, we again sampled in Simpson Cove, Kaktovik, Jago, and Beaufort lagoons.

We designed this study to examine fish assemblages in the sampling areas as a community. We used a relative abundance indicator, catch per unit effort (CPUE) and identified five "target species" for analyses of specific population parameters. The five species were Dolly Varden char *Salvelinus malma*, Arctic cisco *Coregonus autumnalis*, Arctic cod *Boreogadus saida*, fourhorn sculpin *Myoxocephalus quadricornis*, and Arctic flounder *Pleuronectes glacialis*. Previous studies indicated these species were appropriate for additional study (West and Wiswar 1985; Wiswar and West 1987). Target species represented anadromous and marine species that were: (1) present at all sampling areas, (2) generally abundant, (3) readily sampled by fyke and gill nets, or (4) important for subsistence or commercial fishing (Dolly Varden char and Arctic cisco).

Specific objectives of this five-year study were to:

(1) Determine relative abundance, distribution, and movement patterns for anadromous and marine fish species.

(2) Investigate length frequency, age structure, weight-length relationships, and condition for Dolly Varden char, Arctic cisco, Arctic cod, fourhorn sculpin, and Arctic flounder in Arctic Refuge coastal waters.

(3) Characterize the sampling areas in terms of water temperature and salinity.

(4) Delineate current patterns offshore from the Simpson Cove and Beaufort Lagoon sampling areas.

(5) Examine the relationships of salinity, temperature, and current patterns to wind direction and velocity in the sampling areas.

(6) Test the hypothesis that relationships exist between CPUE and hydrographic characteristics; and determine the nature of these relationships.

Our report summarizes fisheries data from 1988 to 1991 sampling activities, objectives one and two. In addition, it describes methodology used to collect hydrographic data. Service personnel collected hydrographic data and used portions of it to address objective six. The National Oceanic Atmospheric Administration (Hale 1990, 1991) and University of Alaska, Environmental and Natural Resources Institute (ENRI, in preparation) published separately detailed descriptions of hydrographic data collection methodology, analyses, and results (objectives three to five).

Study Area

Each year we sampled four areas in Arctic Refuge coastal waters for fish and hydrographic data. Sampling areas included: Simpson Cove, Kaktovik and Jago lagoons, Pokok Bay, and Beaufort Lagoon (Figures 1.2-1.5). The westernmost sampling area, Simpson Cove, rests within Camden Bay (Figure 1.2) and is approximately 43 km southwest of the village of Kaktovik. Camden Bay is a broad open-water zone along the Arctic Refuge coast extending between the Canning River delta (Figure 1.1) and Anderson Point (Figure 1.2). Collinson Point, a sand/gravel spit extending into Camden Bay, partially encloses Simpson Cove where maximum depth is approximately 3.4 m (Nautical Chart 16044, U.S. Department of Commerce).

East of Collinson Point, Camden Bay consists of a broad bight extending southeastward and then curving northeastward toward Anderson Point. Clough et al. (1987) identified this bight area as a possible port site should oil and gas developments occur. The ocean bottom in this part of Camden Bay drops off sharply, reaching depths of 6 m within 0.5 km from the shore (Nautical Chart 16044, U.S. Department of Commerce). The bottom gradient decreases offshore, reaching a depth of 9 m approximately 5 km from shore (Nautical Chart 16044, U.S. Department of Commerce). Most of the Camden Bay shoreline is sand/gravel beach at the base of tundra bluffs 1-2 m high, although in some areas these bluffs may be as high as 3-5 m.

The major stream drainages discharging into Camden Bay are the Katakturuk River and Marsh and Carter creeks. Several unnamed smaller streams also drain into the bay. Other major rivers nearby include the Canning River to the west and the Sadlerochit and Hulahula rivers to the east.

The Kaktovik and Jago lagoon sampling areas are located southeast of Barter Island (Figure 1.3). Barter Island forms the western and northern shores of Kaktovik Lagoon. Jago Lagoon is east of Kaktovik Lagoon and divided from it by a low sand/gravel spit between the mainland and an island locally known as Manning Point or Drum Island. Occasionally the two lagoons become contiguous when the spit is inundated during periods of high water. Jago Lagoon is separated from the Beaufort Sea by a barrier island, Bernard Spit. The Jago River delta forms the eastern shore of Jago Lagoon.

Jago Lagoon is a limited exchange lagoon (Hachmeister and Vinelli 1984). Limited alongshore marine water exchange occurs via two openings in the barrier island system to the Beaufort Sea. One is in the western part of the lagoon between Barter Island and Bernard Spit. The other, known as Jago Entrance, is a much broader opening to the Beaufort Sea near the Jago River delta between Bernard Spit and Jago Spit. Jago Lagoon is connected to another lagoon to the east by a shallow expanse of water between the Jago River delta and Jago Spit. The Jago River is the only prominent stream draining into Jago Lagoon.

Kaktovik Lagoon is a pulsing lagoon, where tide and wind facilitate water exchange (Hachmeister and Vinelli 1984). It has two channels leading to other waters. The primary channel, known as Nelsaluk Pass, connects

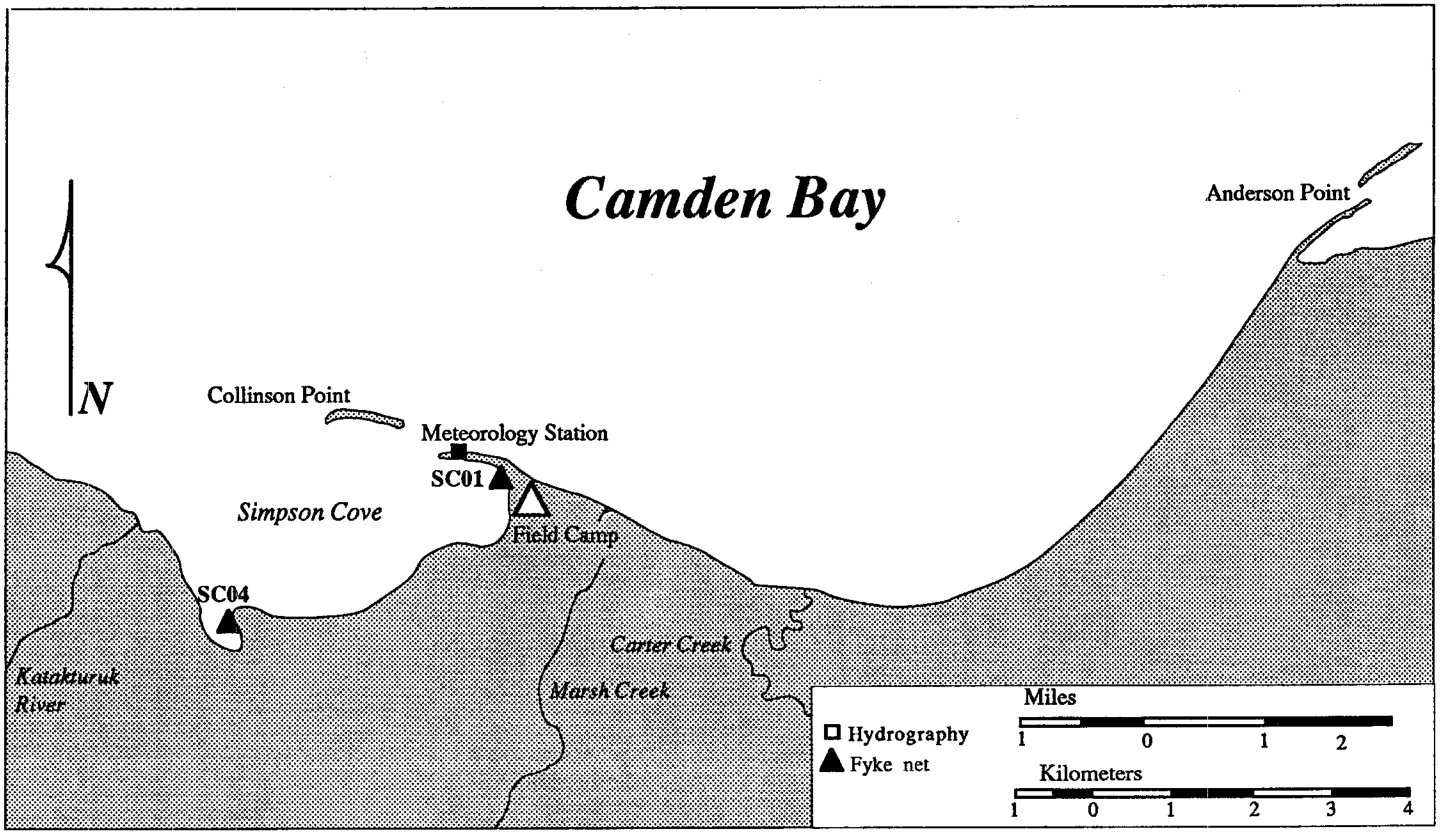

FIGURE 1.2– Simpson Cove sampling area within Camden Bay, Arctic Refuge coastal waters, 1988-91.

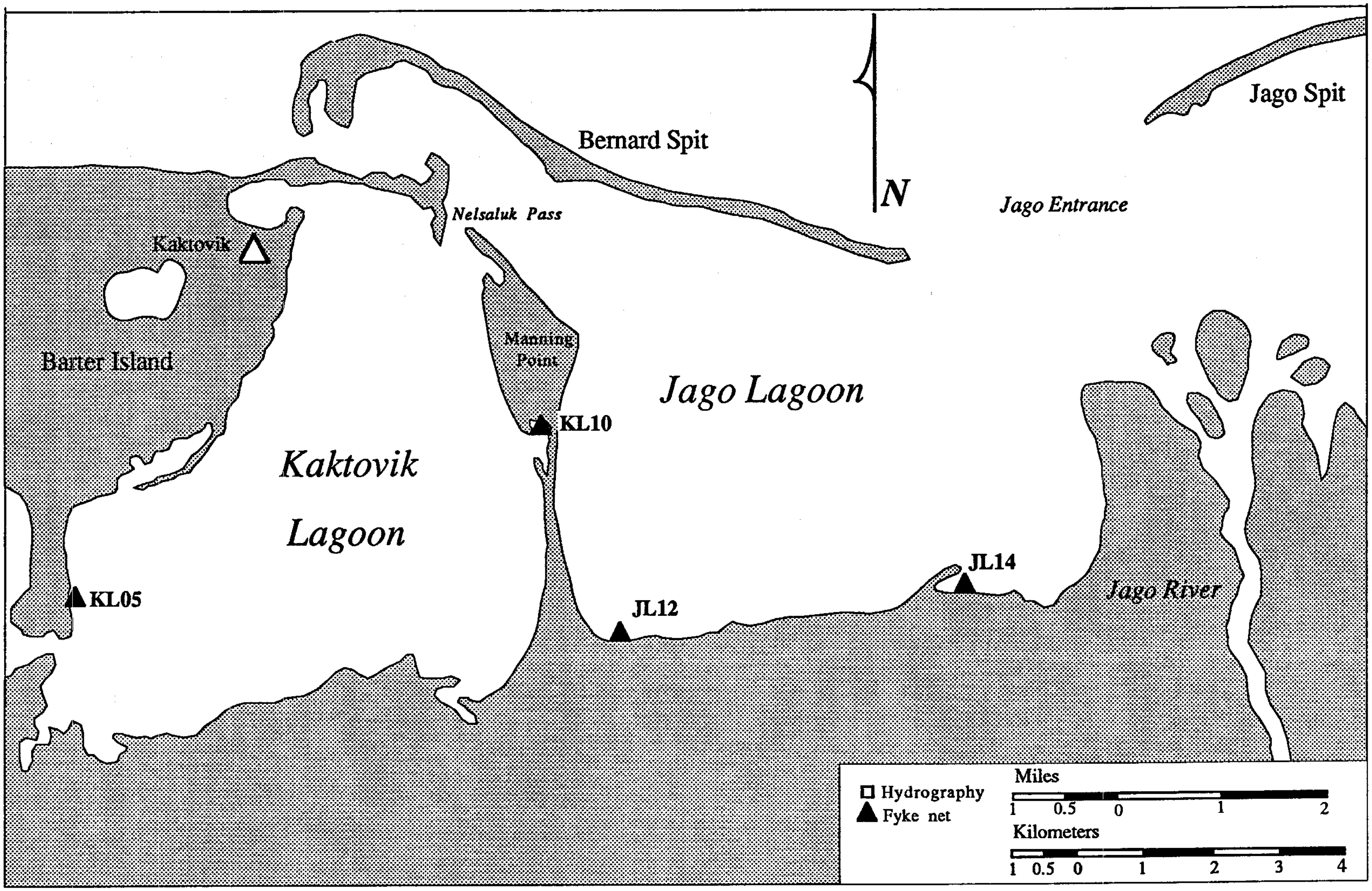

FIGURE 1.3— Kaktovik and Jago lagoons sampling areas within the Arctic Refuge coastal waters, 1988-91.

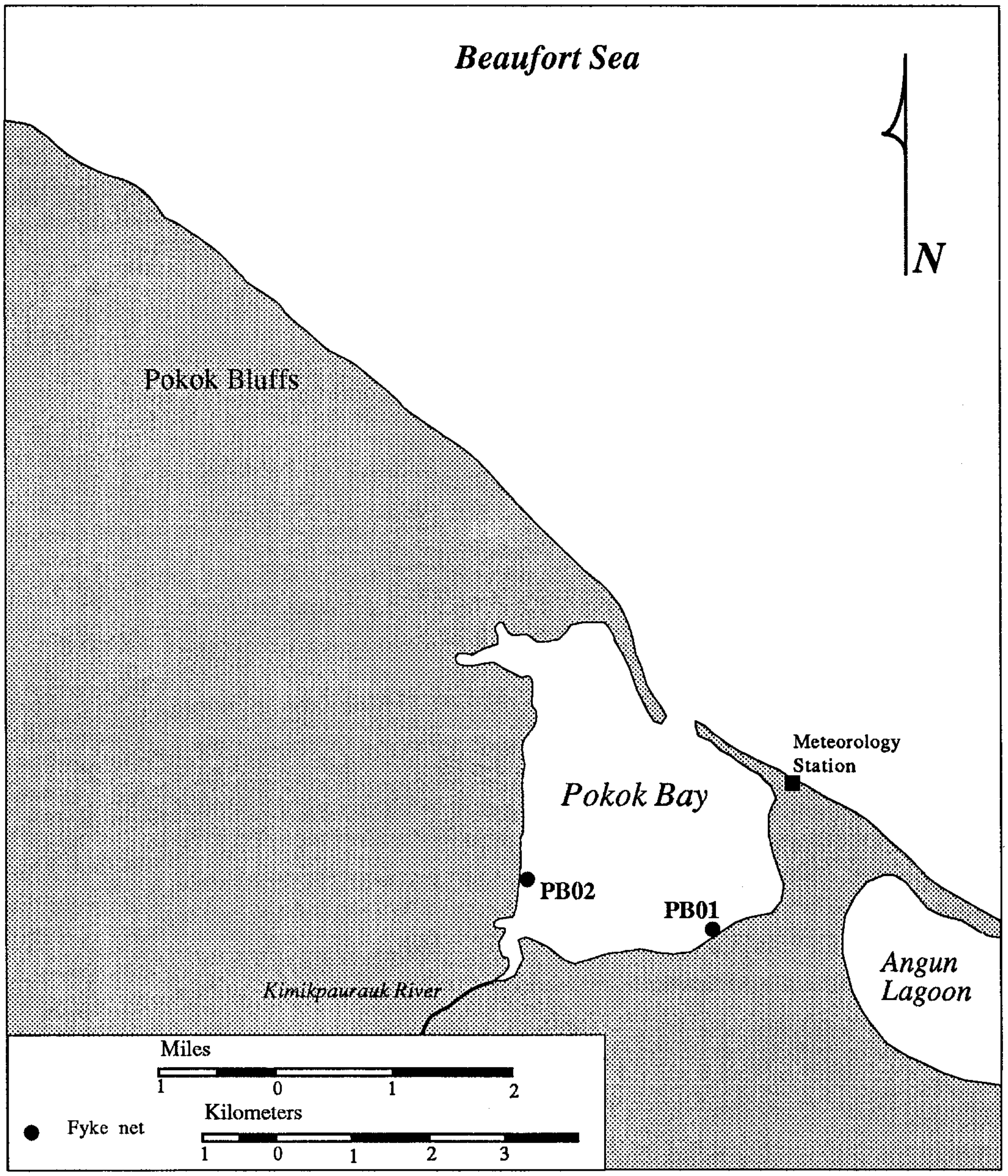

FIGURE 1.4— Pokok Bay sampling area within the Arctic Refuge coastal waters, 1988.

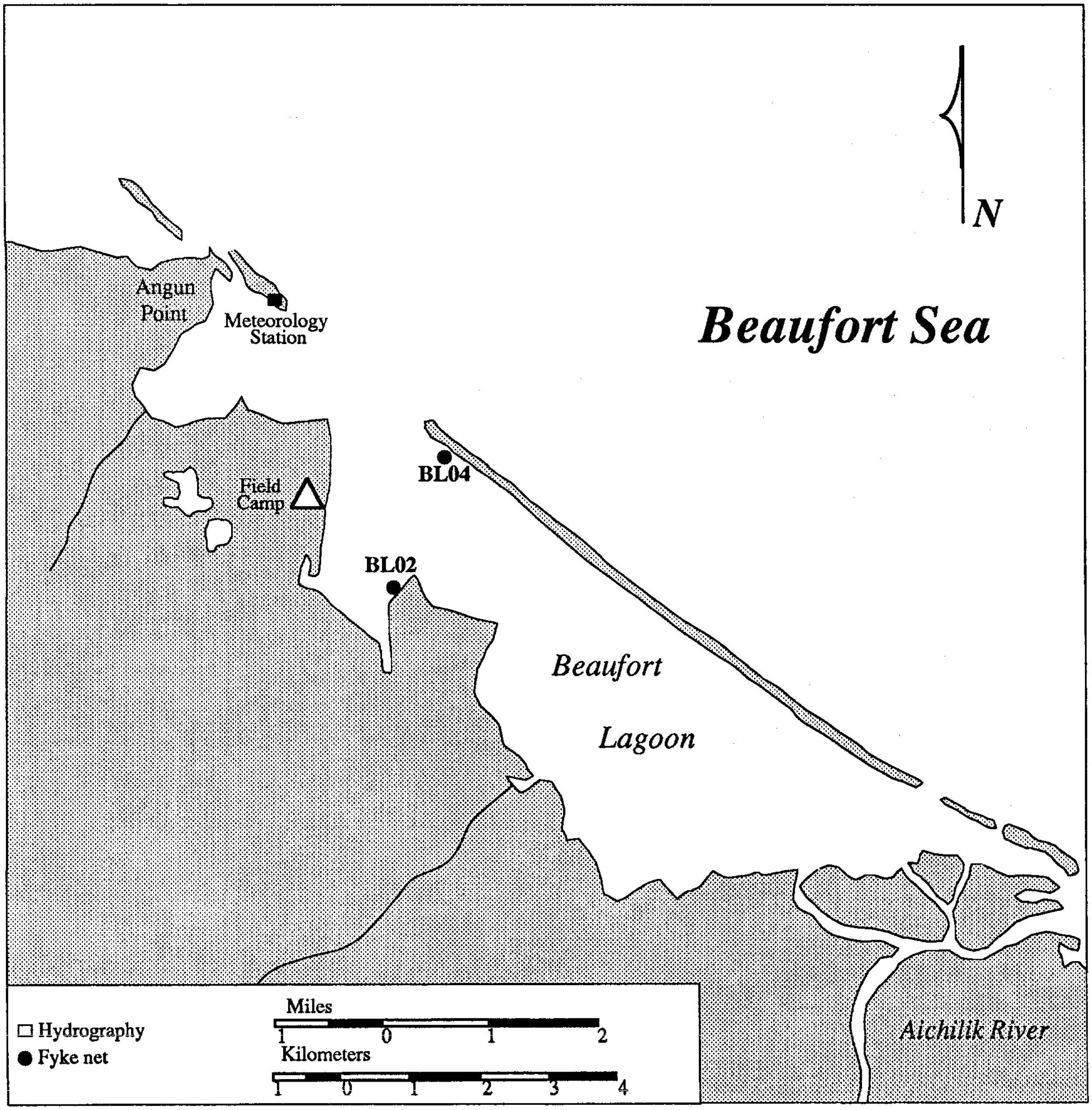

FIGURE 1.5— Beaufort Lagoon sampling area within the Arctic Refuge coastal waters, 1989-91.

Kaktovik and Jago lagoons. Another shallow channel at the southwest end of Kaktovik Lagoon opens to waters west of Barter Island. No large streams empty into Kaktovik Lagoon.

Maximum water depth in Kaktovik and Jago lagoons is approximately 4 m (Nautical Chart 16043, U.S. Department of Commerce). Most of the shoreline of these two lagoons is physically similar to that described for Simpson Cove, being sand/gravel beach below tundra bluffs. The southwestern shore of Kaktovik Lagoon has less beach area and the bluffs are lower in elevation than most areas of the lagoon.

The Pokok Bay sampling area (Figure 1.4) is approximately 43 km southeast of Kaktovik. This bay has a single narrow opening to the Beaufort Sea and is best described as a small pulsing lagoon (Hachmeister and Vinelli 1984). Maximum depth is approximately 4 m (Nautical Chart 16042, U.S., Department of Commerce). Hachmeister and Vinelli (1984) summarized physical and hydrographic characteristics of this small lagoon. One major tundra stream, the Kimikpaurauk River, flows into Pokok Bay. The shoreline is sand/gravel beach below tundra bluffs.

The Beaufort Lagoon sampling area (Figure 1.5) is approximately 55 km southeast of Kaktovik and extends from Angun Point eastward to the Aichilik River delta. This sampling area comprises a series of small interconnected narrow lagoons extending eastward to Demarcation Bay. Hachmeister and Vinelli (1984) described Beaufort Lagoon as a limited exchange lagoon. Maximum water depth in Beaufort Lagoon is approximately 4 m (Nautical Chart 16042, U.S. Department of Commerce). Most of the lagoon shoreline is sand/gravel beach below tundra bluffs.

Hale (1990, 1991) provides additional information on the hydrographic characteristics of Simpson Cove, Kaktovik and Jago lagoons, Pokok Bay, and Beaufort Lagoon.

Methods

Sampling Gear

Within each sampling area, we operated two standard fyke nets per year. We placed fyke nets in coves and protected nearshore areas in water depths of 1.3 m or less (Figures 1.2-1.5 and Table 1.1). Nets were fished from approximately mid-July through mid-September. Beaufort Lagoon replaced Pokok Bay as a sampling area in 1989. We checked fyke nets daily during sampling unless severe weather precluded safe boat travel.

In 1988, we established a fyke net station (SC01) in the semiprotected waters of Simpson Cove. In 1989, we set up an additional net station, SC04. We selected these stations because they had been successfully fished in 1987; therefore, additional data could be added to that baseline (D. W. Wiswar, U.S. Fish and Wildlife Service, personal communication).

We originally selected fyke net stations in Kaktovik (stations KL05 and KL10) and Jago lagoons (stations JL12 and JL14) because they were near

TABLE 1.1– Fyke net station designations and locations by sampling area.

Station	Latitude	Longitude
	Simpson Cove	
SC01	69° 58.98′ N	144° 50.20′ W
SC04	69° 57.66′ N	144° 57.00′ W
	Kaktovik Lagoon	
KL05	70° 05.44′ N	143° 39.56′ W
KL10	70° 06.59′ N	143° 31.00′ W
	Pokok Bay	
PB01	69° 57.65′ N	142° 32.40′ W
PB02	69° 58.17′ N	142° 34.55′ W
	Jago Lagoon	
JL12	70° 05.22′ N	143° 28.50′ W
JL14	70° 05.51′ N	143° 22.23′ W
	Beaufort Lagoon	
BL02	69° 53.28′ N	142° 18.59′ W
BL04	69° 54.35′ N	142° 17.23′ W

potential fish pathways and they represented the typical habitat of these sampling areas. After floating ice proved problematic in the first weeks of 1988, we relocated two stations, KL10 in Nelsaluk Pass and JL14 on the northeast side of Manning Point. Their new locations were in protected coves making them less vulnerable to ice, but placing them farther from the expected fish pathways (D. W. Wiswar, U.S. Fish and Wildlife Service, personal communication).

We placed Pokok Bay fyke net stations, PB01 and PB02, in habitat representative of the sampling area and suitable for fyke net deployment. Pokok Bay was sampled only in 1988.

Beaufort Lagoon fyke net stations, BL02 and BL04, were identical to those of previous studies (West and Wiswar 1985; Wiswar and West 1987). We fished these nets first in 1989 during three periods, July 18-24, August 11-17, and September 2-10. In 1990 and 1991, fyke nets were fished continuously during the open water season.

Standard fyke nets consisted of two adjacent traps each constructed of 1.5-m wide and 1.2-m high frames at the mouth. The mesh sizes were 12.5-mm stretch for the traps and 25-mm stretch for the wings and leads. One 61-m lead was anchored between the two traps with the 15-m wings extending from the frames' outside edges opposite to the lead. The lead was set perpendicular to the shoreline with one end anchored to shore and set traps offshore (Figure 1.6). We configured the fyke net such that fish approaching the net were trapped in the cod end on the side in which they entered. During sampling, leads were fully extended on all standard fyke nets, except at station KL10, where the lead only extended 30 m due to the steep bottom gradient. We anchored traps, leads, and wings in place using solid steel rods (3-m length and 1.5-cm diameter).

Relative Abundance and Distribution

Sample Processing.— We enumerated all fish captured by species. To estimate the number of fish in unusually large catches (> 1000 individuals) we counted the number of fish in three subsamples. A subsample consisted of the volume required to fill a container to a prescribed level. Before obtaining each subsample, we randomly mixed the catch. The average number of fish in the three counted subsamples was multiplied by the total number of subsamples to estimate the entire catch. All fish were released except those sacrificed for other analyses. To avoid immediate recaptures, we released fish offshore, away from the net site.

Catch Data Analyses.— To calculate daily total catch we combined catches in adjacent cod ends at each station by species. We adjusted daily effort for each species to 24 h and calculated relative abundance of each species as catch per unit effort (CPUE) by day (date of net processing). For each station and species, daily fyke net CPUE was calculated by dividing the adjusted effort into catch. We calculated seasonal fyke net CPUE for non-target species and for the data appendices, by dividing the sum of total seasonal catch by the sum of total adjusted seasonal effort. Due to discrepancies in sampling protocol, we removed observations from the 1988 field season for all locations for Arctic cisco and from the 1989 field season in Beaufort Lagoon for all species.

We used a two-step process to investigate spatial and temporal variation in catch. Our first approach was two-way analysis of variance (ANOVA) employing log-transformed data from all years and sampling areas. To identify the major source of variation in the overall data set, year, sampling area, and the interaction term were included in the model. We assumed that departures from normality and heteroscedasticity were sufficiently overcome by the transformation ($\log_e$ (CPUE+1)) and the robustness of the ANOVA procedure. To further clarify CPUE trends, Tukey means comparisons were used on the transformed data.

We detected differences in CPUE between treatment groups (net stations, sampling areas, time periods, etc.) for each species using Kruskal-Wallis nonparametric tests. If differences were detected, Scheffé multiple comparisons were used to determine which locations differed. All tests were run at the $\alpha = 0.05$ significance level. For each species, we tested spatial differences, and intra-annual differences between stations and areas of CPUE. We also tested temporal differences of CPUE, intra-annual between time periods at a given station or area, for each species. The four time periods included: (1) the first sampling day to July 31; (2) August 1-14; (3) August 15-31; and (4) September 1 to the last sampling day. We also compared inter-annual differences in CPUE within area, net station, and time period.

Catch per unit effort trends were depicted graphically with Tukey boxplots (box-whisker plots). The boxes span the 25th and 75th percentile points of the data, with the median line enclosed. The whisker-caps span the 10th and 90th percentile points and the filled circles indicate the interpolated 5th and 95th percentile points.

Length Frequency Distributions

Using standard fyke net data, we generated length frequency distributions for the five target species (Dolly Varden char, Arctic cisco, Arctic cod, fourhorn sculpin, and Arctic flounder) at each sampling area. We measured fork lengths (FL) for Dolly Varden char, Arctic cisco, and Arctic cod and total lengths (TL) for fourhorn sculpin and Arctic flounder. For each species present in a trap, lengths of at least 25 randomly-selected individuals (50 individuals in 1990) were measured to the nearest millimeter. When catch totaled 25 or less (50 or less in 1990), we measured all individuals. Fyke net length data were plotted for each species by four periods: (1) the first day of sampling to July 31; (2) August 1-15; (3) August 16-31; and (4) September 1 to the last day of sampling. We described the first and second significant peaks in abundance on the left side of the distribution as "primary mode" and "secondary mode", respectively.

Fish Condition

For the five target species, we examined fish condition (weight of a fish at a given length) and form (rate of increase in weight as a function of

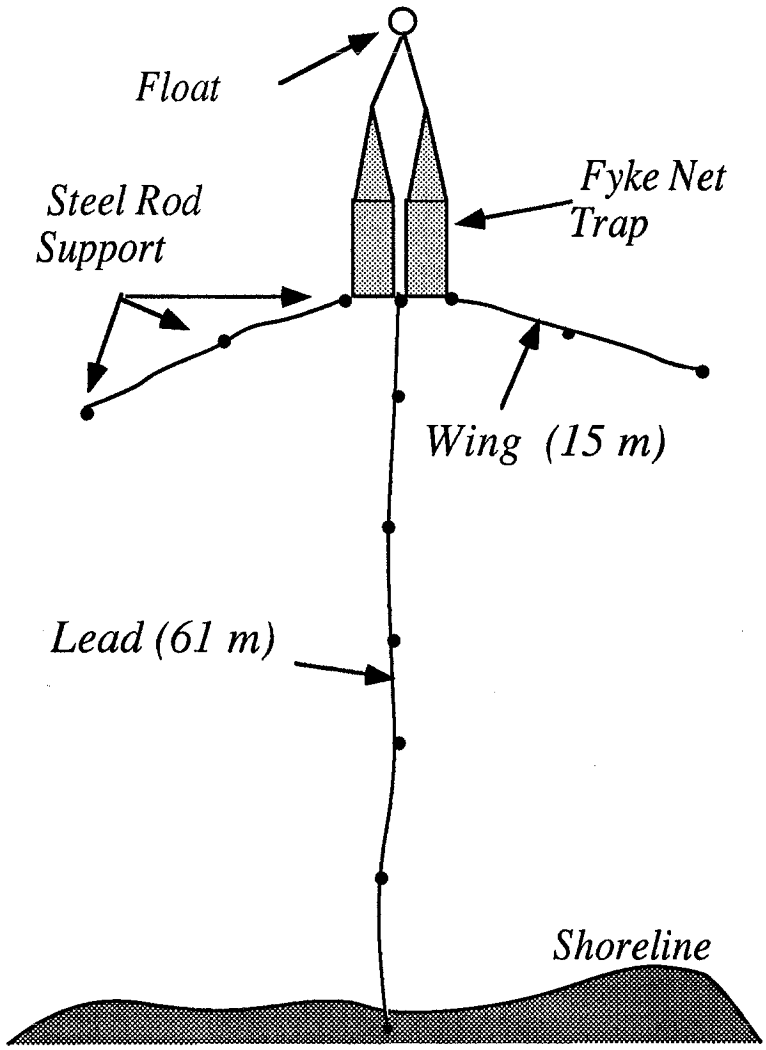

FIGURE 1.6— Standard fyke net configuration.

length) (Cone et al. 1990) following Cone's (1989) method of least squares regression. We conducted the following five tests:

(1) Gender-based differences in condition were tested by comparing female and male fish collected in July for data from all years pooled.

(2) Seasonal differences in condition were tested by comparing fish collected early in the open water season (July 10-24) against those collected late in the season (August 2-September 12), for all years combined and within individual years.

(3) Overwintering differences in condition were tested by comparing fish collected after August 27 of one year against fish collected in July of the following year. We analyzed data from the winters of 1988-89, 1989-90, and 1990-91 separately.

(4) Among-area differences in condition were tested by comparing fish collected within each sampling area (with all years combined) and within each individual year. We conducted tests separately on fish collected in July and those collected after August 27.

(5) Among-year differences in condition were tested by comparing fish collected from each year with all areas combined and within each individual sampling area. We conducted tests separately on fish collected in July and those collected after August 27.

Because of changes in personnel and project goals, sampling regimes were modified over the four years of data collection. In 1988, we did not stratify the subsample used to measure condition by length groups, although an effort was made to sample from the entire length range. After 1988, we stratified by length to sample length intervals evenly and avoid bias in parameter estimates. Before the 1988 and 1989 field seasons we set subsample target numbers; during these field seasons we coordinated data collection between sampling areas by radio to obtain a single sample. In 1990 and 1991, the subsampling by length and sampling area were stratified making each area independent (three separate samples, Kaktovik and Jago lagoons as one sample) and increasing the total number of fish sampled.

Data for the comparison of condition between sexes were collected only at Simpson Cove and Beaufort Lagoon. We selected 10-mm length intervals for all species except Dolly Varden char. Due to their large size range, 25-mm intervals were used for Dolly Varden char (Anderson and Gutreuter 1983). Depending on the year, we collected five or eight fish from each length interval. We measured fish lengths as described above. Using an electronic balance, fish less than 500 g (1 kg in 1991) were weighed to the nearest g. To weigh larger fish, 500 g (1 kg in 1991) or more, we used

Pesola spring scales to different levels of precision depending upon fish size. Weights between 1 and 2 kg were measured to the nearest 50 g and weights greater than 2 kg to the nearest 100 g.

We calculated the least squares regression using the SAS GLM procedure and comparisons using an analysis of covariance procedure (SAS Institute Inc. 1988). A standard natural logarithm transformation was used to linearize the data and stabilize variances. This procedure allowed the separate evaluations of slopes and intercepts. We screened data sets for outliers, defined as studentized residual values greater than absolute four (Neter et al. 1990), and ran statistical procedures with and without outliers.

Differences in condition were recognized only when body form was constant, slopes were not different, and differences in intercept were significant. If slopes differed, we considered body form changed and made no statement about condition (Cone et al. 1990). When differences in condition were significant, tests of full and reduced models were used (Neter et al. 1990) for pairwise comparisons to further distinguish between three or more groups. For example, the among-area comparisons included three groups. The full and reduced model were as follows:

full model,

$$W = \beta_0 + \beta_1 L_1 + \beta_2 X_1 + \beta_3 X_2 + \beta_4 L_1 X_1 + \beta_5 L_1 X_2 + \epsilon_i;$$

reduced model,

$$W = \beta_0 + \beta_1 L_1 + \beta_2 (X_1 + X_2) + \beta_3 L_1 (X_1 + X_2) + \epsilon_i;$$

where,

W = the natural logarithm of weight;
L = the natural logarithm of length;
β_0 = the y-axis intercept;
β_1 = the slope;
$\beta_{1\text{-}4}$ = coefficients of the model parameters;
X_i = dummy variables representing the areas being compared;
ϵ = the error term.

The test statistic is calculated as:

$$F* = \frac{SSE(R) - SSE(F)}{df_R - df_F} \div \frac{SSE(F)}{df_F};$$

where,

$F*$ = the calculated F-ratio;

SSE(F) = sum of squares error full model;
SSE(R) = the sum of squares error reduced model;
$df_{(F)}$ = degrees freedom of the full model;
$df_{(R)}$ = degrees of freedom reduced model;

(Neter et al. 1990). All tests were run with $\alpha = 0.05$ significance level. If the data sets contained less than the minimum of 32 observations, we dropped them from our analyses.

Age and Growth

Collection of Age Samples.– To avoid effects of within-season growth on the analyses, growth analyses were run using only fish collected during July. Over the sampling seasons, we collected one to five of the target species in each size interval depending on the year.

In 1988, five target species were collected during July. Twenty fish of each species were subsampled. We selected fish over the range of lengths present in the catch. After 1988, we attempted equal sampling of 10-mm length intervals (25-mm intervals for Dolly Varden char) for each species by collecting five or eight fish from each length interval. In 1989, from July 10-24, we collected five target species in Simpson Cove, Kaktovik and Jago lagoons. In 1990, we collected Arctic cisco < 250-mm FL in all sampling areas for growth analyses. During this year, eight fish per length interval were sampled. No Arctic cod were captured in 1991, therefore, we only sampled four target species. In 1991, samples were taken at the remote camps of Simpson Cove and Beaufort Lagoon.

Age Determination.– We removed sagittal otoliths, stored them in isopropyl alcohol, and determined age 2 to 3 months later at the Fairbanks field office. Our methodology followed Barber and McFarlane (1987). Using a fiber optic light we illuminated whole otoliths and viewed them at low magnification through a dissecting microscope. We assigned ages based on at least two independent readings. If ages could not be assigned using surface reading techniques, we broke otoliths through the nucleus and burned them in an alcohol flame before viewing. If no agreement could be reached for a given pair of otoliths after two independent examinations, a third reader attempted to age the pair. If no consensus was reached among the three readers or if the otoliths were unreadable, the sample was rejected.

Data Analysis.– We performed Kruskal-Wallis nonparametric analyses to test the hypotheses of no significant differences in length at age among years with areas pooled and among areas with years pooled. In addition, age frequencies from the age sample and length frequencies from the fyke net data set, stratified by year, were examined to determine if they corresponded.

Fish Movements

To gather information on fish movements, we marked fish with dyes and external tags. Marking and tagging methodology varied by year. We recorded marks and tags at release and upon recapture.

1988.— We marked salmonids greater than 80 mm FL either with a fin clip or with alcian blue dye applied with Syrijet® Mark III dental injectors (Mizzy Inc.). Fish marked at the three different sampling sites were distinguished by clipping or applying dye at the base of different fins as follows: Simpson Cove, left pelvic; Pokok Bay, right pelvic; Kaktovik and Jago lagoons, adipose clip or caudal peduncle mark. Using numbered, fluorescent, orange anchor tags we marked individuals of other common species greater than 250 mm length. Local village residents objected to tagging, therefore, we used fin marks on anadromous species. However, some individuals of these species were tagged in September when disturbance by tagging would be minimized.

1989.— We marked juvenile Arctic cisco less than 250 mm FL using alcian blue dye applied with the dental injector. Fish marked at the four different sampling areas were distinguished by applying dye at the base of different fins as follows: Simpson Cove, left pelvic; Beaufort Lagoon, right pelvic; and Kaktovik and Jago lagoons, left caudal peduncle.

1990 and 1991.— With a dental injector, we marked Arctic cisco and Dolly Varden char, less than 300 mm FL, using black India ink (1990) and alcian blue dye (1991). As in 1989, we applied dye marks according to sampling area. Dolly Varden char and Arctic cisco greater than 300 mm FL and other target species greater than 200 mm length received Floy anchor tags.

Environmental Influences on CPUE

Coincident with the collection of daily CPUE data, we collected water temperature and salinity depth profiles at each fyke net station with a SeaBird Electronics SBE-19 Seacat Profiler (CTD). To minimize bias by extreme values resulting from localized stratification of the water column (Hale 1991) or improper CTD recording protocol, the data from each CTD cast were filtered. We calculated mean daily temperature and salinity at each station as the mean of those values remaining after values included in the bottom and top twenty-fifth percentiles were excluded from the data stream.

Wind speed (m/s) and direction (source) data were retrieved from various Service meteorologic stations located along the Arctic Refuge coastline, including Simpson Cove (1988-89, 1991), Barter Island (1989), Beaufort Lagoon (1990-91), and Pokok Bay (1988). Hale (1991) found wind speed and direction time series for these and other coastal sites were generally consistent across stations, with only small discrepancies. Depending on availability, we combined data from different stations across years to complete the wind record for coastal Refuge waters. Wind speed and direction data were corrected for declination and linearized by trigonometric decomposition of the angular vector into north and east vector components as described by Zar (1984), followed by calculation of overall mean daily vectors. North and east wind vectors were positive when source directions were between 270°-90°, and 0°-180°, respectively, and were negative otherwise.

Available water current data were limited; therefore, we did not use these data in the integrative analyses of physical variables and catch data. Water currents along the Beaufort Sea coast are primarily wind-driven (Craig 1984; Fechhelm and Griffiths 1990; Hale 1990), with water current shifts often following wind shifts within 2 to 3 h (Hale 1990). From these results, we assumed any effects of water currents on daily CPUE trends could be assessed through integration of wind patterns and CPUE.

We matched daily CPUE estimates for each target species by date with the station mean daily temperature and salinity and the mean daily wind vectors from the nearest meteorologic station. To assess possible time-delayed associations between catch and wind patterns north and east wind vectors were generated for one day before the observed CPUE and the mean north and east wind vectors for the three days preceding the observed CPUE. We used standard graphical and correlation techniques to explore for univariate associations between CPUE and the physical variables. To test for differences in temperature and salinity between sampling areas by years ANOVAS (Scheffe's multiple comparison) were performed. Stepwise regression (SAS 1988) was used to identify those physical variables that best explained the observed variation in the CPUE data, by (fyke net station × year) and (sampling area × year) combinations for each target species. The stepwise algorithm systematically included and/or deleted independent variables according to progressive comparisons of main effect P-values against a predetermined threshold level ($P = 0.10$).

Hydrographic and Meteorologic Sampling

We augmented the depth profiles of salinity and temperature collected at fyke net stations with data from various stations within the study area (Table 1.1 and Figures 1.2-1.5). Moored current meters collected continuous records of salinity, temperature, current direction, and current velocity offshore in Camden Bay, and at Carter and Marsh creeks. Researchers synthesized these hydrographic data, and the wind data from the coastal meteorologic stations, for each sampling area in separate annual reports (Hale 1990, 1991; ENRI, in preparation).

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